

**SENSING AND CONTROL FOR A BIO-MIMETIC RECONFIGURABLE  
ANTENNA SYSTEM BASED ON PHOTOSYNTHETIC ATTRACTION**

An Undergraduate Research Scholars Thesis

by

MELANIE MARIE ENRIQUEZ

Submitted to the Undergraduate Research Scholars program at  
Texas A&M University  
in partial fulfillment of the requirements for the designation as an

UNDERGRADUATE RESEARCH SCHOLAR

Approved by Research Advisor:

Dr. Gregory Huff

May 2018

Major: Electrical Engineering

# TABLE OF CONTENTS

	Page
ABSTRACT.....	1
DEDICATION.....	2
ACKNOWLEDGMENTS .....	3
NOMENCLATURE .....	4
CHAPTER	
I.    INTRODUCTION .....	5
Automating Antenna Movement: ESPAR.....	5
Research Goals and Approach .....	7
II.   METHODS .....	8
Antenna Arrays .....	8
Single Monopole: HFSS Software.....	9
Yagi-Uda Network: HFSS Software.....	11
DC Offset/Signal Maximization .....	13
Control Circuit: ANSYS Circuit Simulator .....	15
III.  RESULTS .....	17
Wave Maxima.....	17
Monopole Characterization.....	17
3 Identical Monopoles in Parallel: Characterization.....	19
3 Identical Monopoles: Height Adjustments .....	22
IV.  CONCLUSION.....	23
REFERENCES .....	24

## **ABSTRACT**

Sensing and Control for a Bio-Mimetic Reconfigurable Antenna System Based on  
Photosynthetic Attraction

Melanie Marie Enriquez  
Department of Electrical and Computer Engineering  
Texas A&M University

Research Advisor: Dr. Gregory Huff  
Department of Electrical and Computer Engineering  
Texas A&M University

This paper discusses the concept of replicating biological processes through the use of self-configurable antenna patterns. Through non-linear gradient descent methods and the use of parasitic beam forming, it is proposed that a configured antenna can replicate the photosynthetic attraction of a plant through selective power pattern reception. For characterization purposes, it is necessary to create a microwave tuning circuit to collaborate with an adaptive 2-element yagi-uda antenna network. The two-element network will be used to characterize the parameters for maximum power potential, which will precede the introduction of multiple parasitic array elements and the concept of a reactively controlled directional array. Through multiple beam forming of elements, the centralized antenna will be forced to differentiate between varying power patterns. Circuit tuning and electrical characterization will allow for the centralized antenna to have a self-configurable response mechanism and allow for the ability to position itself for maximum power reception.

## **DEDICATION**

This document is dedicated to my parents for being my greatest support system and joining me in my pursuit for an Electrical Engineering degree. They provide me with daily encouragement and constantly equip me to never settle for less than my best.

In addition, this is dedicated to my friends for constantly encouraging me to stay true to myself in everything that I do.

## **ACKNOWLEDGEMENTS**

I would like to thank Dr.Huff for providing me with the resources available in his lab and for constantly tuning my understanding of RF circuit analyses and antenna design. In addition, I am grateful for the graduate students who have put time aside from their own studies to assist in my own training and development over the course of this research.

## **NOMENCLATURE**

ESPAR	Electrically Steerable Passive Array Radiator
VSWR	Voltage Standing Wave Ratio
HFSS	High Frequency Electromagnetic Field Simulation

# CHAPTER I

## INTRODUCTION

The concept of reactively controlled directional arrays plays a significant role in the simulation of a biomimetic antenna. Much like the photosynthetic attraction and movement of a plant to sunlight, it is proposed that an antenna can do the same, but with ideal power reception. Past experiments have validated the use of reactive loads to manipulate and control antenna radiation characteristics [1]. Through fine-tuning and variability of electrical load distributions, past researchers have enabled automatic antenna control so that they may position it for reception of its maximum signal. This concept has been widely implemented in many fields for adjusting antenna networks. Although very useful, the functionality of directional antennas are limited due to their dependability on external circuits for optimization.

### **Automating Antenna Movement: ESPAR**

For an antenna to relieve itself of external circuit reliability, it must have a way for its movement to be self-automated. Numerous studies highlight the benefits of using Electrically Steerable Passive Array Radiators (ESPAR antennas). In recent studies, it has been confirmed that it is possible to form the main-beam radiation and a beam null in arbitrary directions. This occurs within a horizontal plane by changing the control voltage to the passive element [2]. There are two kinds of parameters in the design of ESPAR antennas: structural parameters, and control parameters, both of which can provide radiation pattern controllability [3]. The structural parameters include the number of passive radiators, active/passive length, and the distance between them. Ultimately, the smart antenna has the capability of adaptive beam forming in accordance to its environment. By controlling and regulating the radiation pattern, the antenna

can achieve its desired performance based on the conditions of the system surrounding it [4]. The network and functional block diagram of these processes are shown in Fig. 1 And Fig. 2.

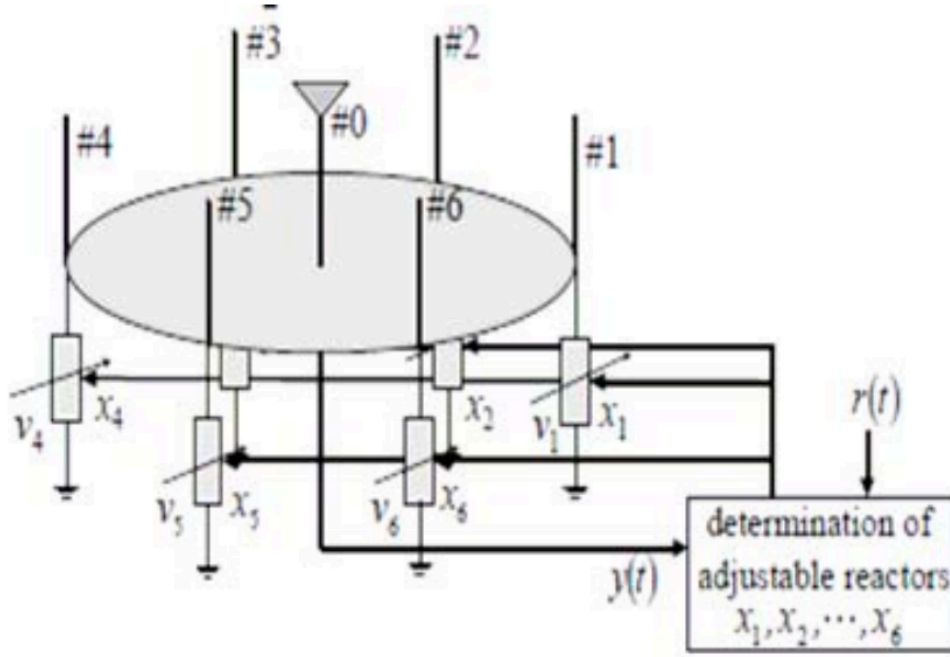


Fig. 1. ESPAR antenna monopole network. The direction circuit works underneath as a control.

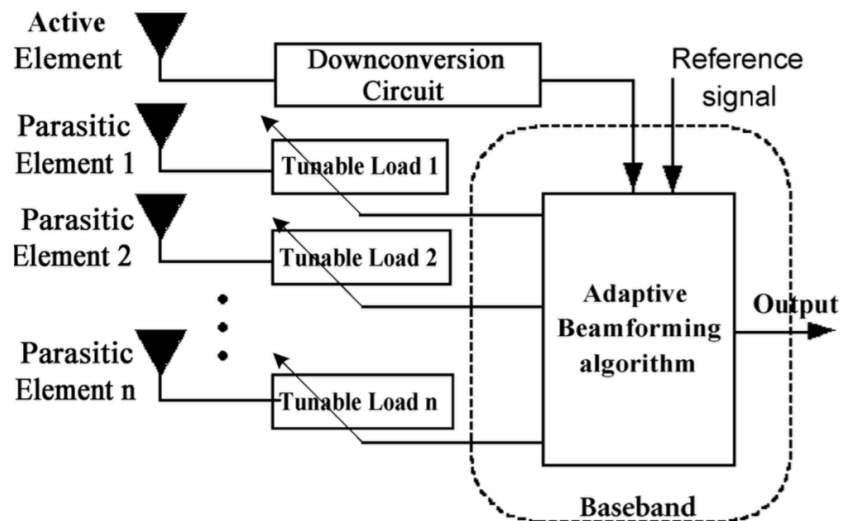


Fig. 2. Functional Block Diagram of ESPAR Antennas



## **Research Goals and Approach**

This thesis presents the design and optimization of RF circuit analysis and antenna simulations. Primarily, the goal is to understand the underlying circuit parameters that are required to accumulate data from incoming wave signals and transfer them into control variables. In doing this, the data can be implemented on a larger scale that will be simulated in ANSYS, a circuit analysis software, and transferred into HFSS for physical implementations in CAD. Upon satisfying adequate results in both ANSYS and HFSS, the actual design of the antenna will be fabricated for real-life testing conditions.

## CHAPTER II

### METHODS

#### Antenna Arrays

Incident angles can be used to feed the circuit for directing radiated power towards a desired angular sector. There are various parameters that are significant to creating a desired angular pattern. Various parameters include the number, geographical arrangement, relative amplitudes and phases of the array elements [5]. Prior to implementing a large-scale design that consists of multiple monopoles and parasitic complexes, there must be a method for characterization. Many different antenna configurations can be utilized as an antenna element in an antenna array [6]. The goal with this project is to characterize a behavior, a control, and a response. The behavior of an antenna is largely due to the environment it surrounds itself in. This itself can vary based off electrical properties of the antenna, or materials within the environment that can promote signal interference. For the purpose of this research, the objective was to merely replicate a 3-element yagi-uda monopole network. In doing this, characterization is simplified as the response can be measured using a limited amount of variables. This particular method allows for simple adjustments, tuning, and identification of extrinsic variable changes. Ideally, through multiple interfering signals, the beam of greatest power reception is the goal for reception (Fig. 3).

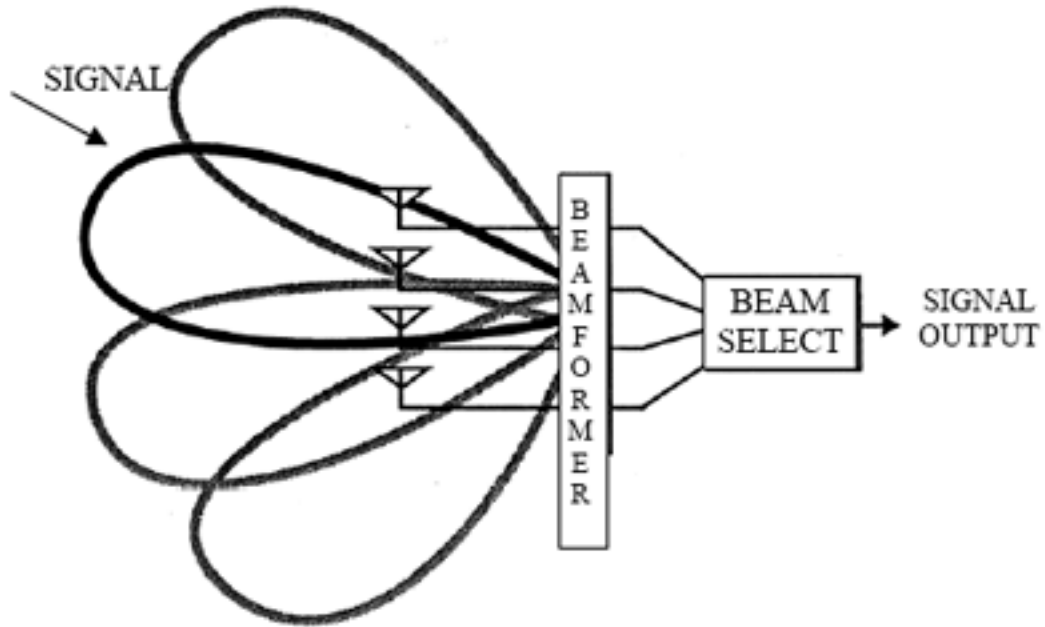


Fig. 3. Switched Multi-Beam Antenna

The control will identify the angle of incidence with greatest power reception. Through wave maximization, the control circuit will identify the change in electrical length (degrees), and modify with the ability to maximize the output magnitude with the appropriate phase shift (in degrees).

#### **Single Monopole: HFSS Software**

Prior to beginning multi-element testing, it was necessary to characterize an individual monopole through HFSS simulation (Fig. 4). In doing this, there is the ability to characterize an ideal length for operation in specific frequencies. To model a cause-and-effect testing method, the physical implementation of the design was implemented into an HFSS CAD-modeling software. This software allows for the repositioning of variables such as distance, impedance, conductivity, length, and other physical antenna parameters. Prior to fabrication, simulations in HFSS eliminate the obstructive time-barrier that comes from reframing various physical

components. A simple model for an individual monopole was developed in HFSS. The frequency sweep was across 2-4GHz, with an optometric sweep varying different monopole lengths to perfectly match the antenna with it's frequency. The antenna was created using a Coax of Teflon material, a useful material that acts like a shield and restricts electromagnetic interference. The bottom of the antenna was surfaced with a perfect electrical conductor, and the monopole itself was simulated with copper material over a ground plane.

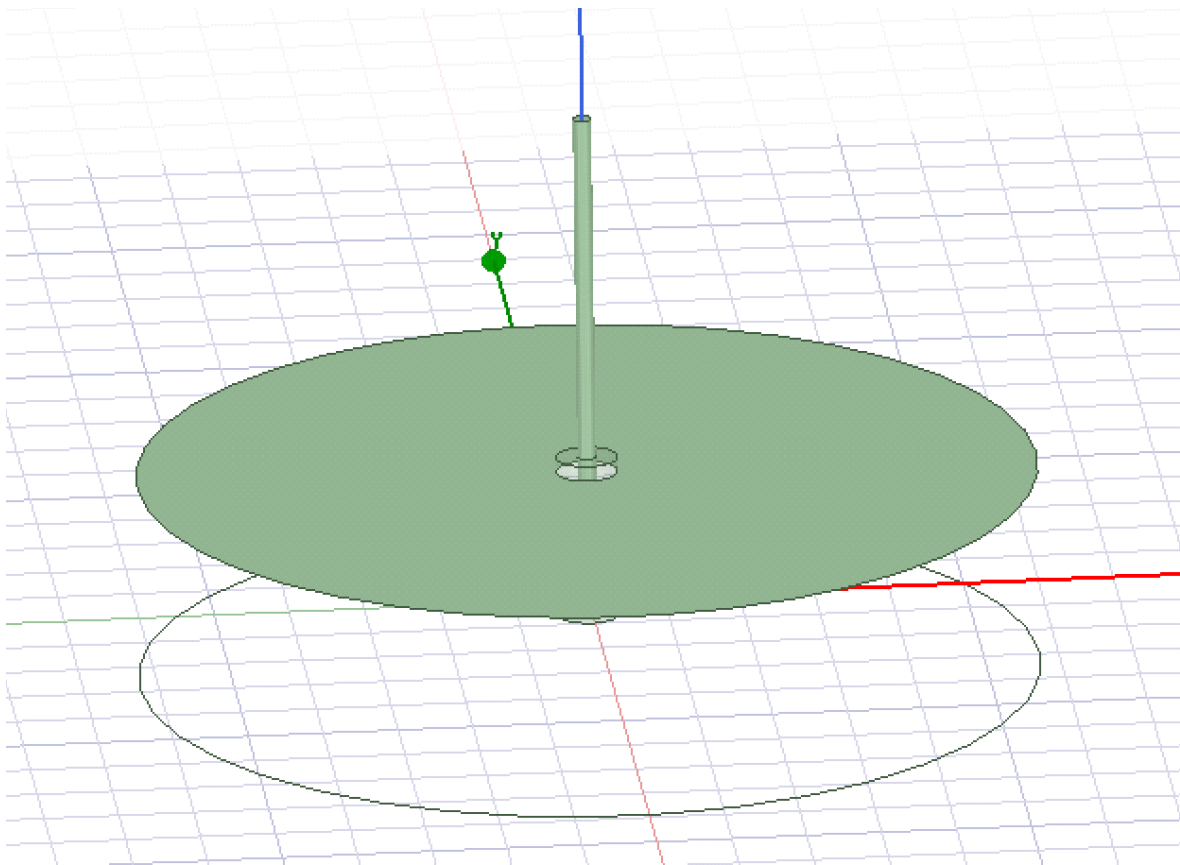


Fig. 4. Individual monopole configured in HFSS

To evaluate the conditions of the simulation and the results, the single monopole developed in HFSS was fabricated for physical testing on the network analyzer (Fig. 5). This was a precedent

in preparation for finalizing the development of a larger-element network that would consist of more parasitic monopoles.

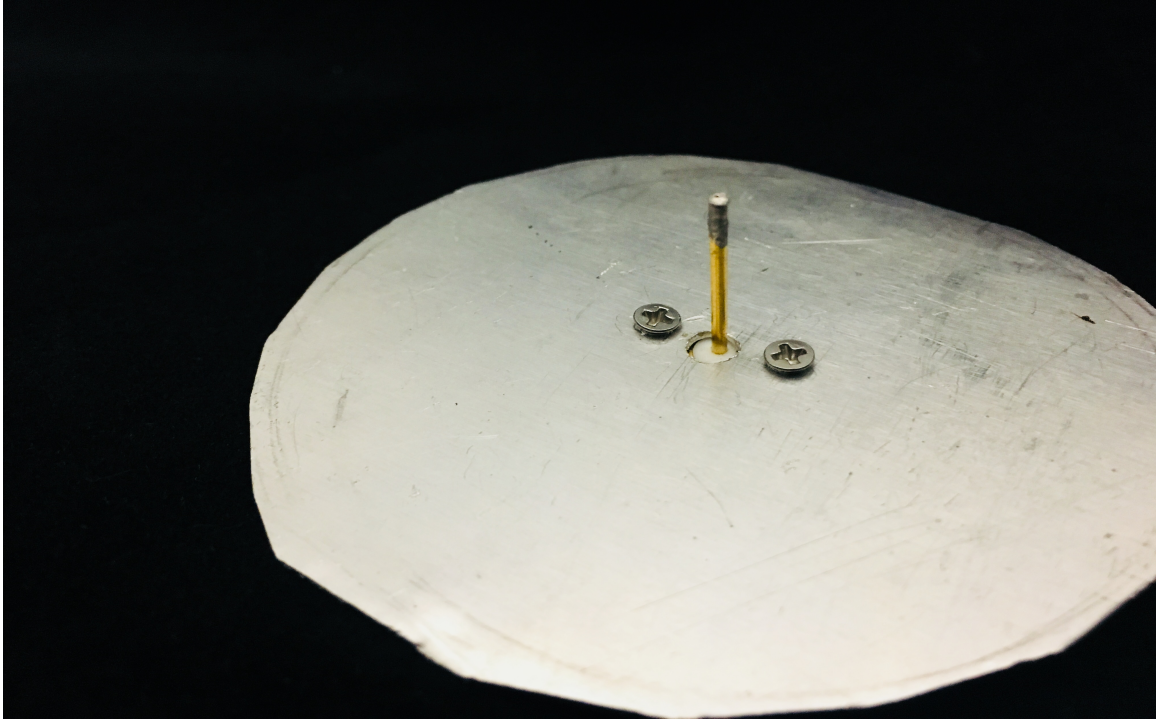


Fig. 5. Fabricated monopole used for physical testing/characterization

### **Yagi-Uda Network: HFSS Software**

To compound on the simplicity of monopoles, the implementation of a 3-element monopole network proves valuable in the characterization and response of physical/electrical parameters. Using the individual monopole as a basis, length was chosen for the ideal frequency of 2.5GHz. In addition, optometric sweeps were implemented to vary distance between the monopoles for further characterization of the configuration's relationship. With three antennas physically simulated, one monopole was center-driven, while the other two elements were short-circuited at their terminals. Due to the mutual impedances with the active monopole, radiation occurs as a set of discrete sources (Greene's Theorem) [7]. This allows for observation of power output and reception between the three antenna elements. HFSS provides applications such as an

interactive smith chart, radiation/power graphs, and linear frequency analyses. These measurement applications were used to measure various height, distance, and impedance parameters while simultaneously allowing them to be reframed. This method was used as a “cause-and-effect” analysis for the most ideal physical design parameters. The HFSS model (Fig. 6) was consistently evaluated using trial-and error analysis in efforts to remove potential electromagnetic ambiguities in conjunction with the RF circuit design.

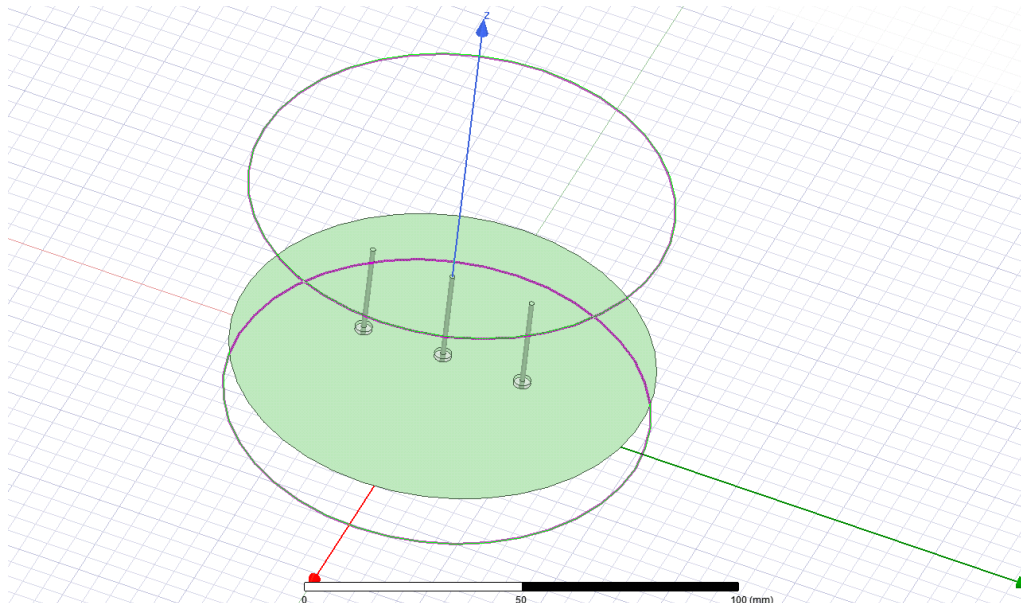


Fig. 6. Three-monopole network configured in HFSS

The three-element parallel network was used as a control. Used as a starting point, HFSS simulations were then run by changing the various heights of dipoles, linear spacing, and degree of tilt (Fig. 7). By analyzing both the distances between director and reflector elements, the performance of power reception was analyzed. By keeping all elements identical, multiple simulations can be run while sweeping distance between each element. This particular method is used to identify the effect of spacing on overall power reception. In addition, there is a desired inductor-capacitor (LC) input that must be found to regulate the behavior of a yagi-uda antenna within changing conditions. This LC input is purely dependent on the nature of electromagnetic

properties. In addition, the LC circuit implementation from ANSYS was used as a control to modify the physical behaviors of the simulation. From the HFSS simulations, the gain of the radiation plots allow for analysis of the front-to-back ratio in response to the tilt (in degree) of the various monopole configurations. HFSS also serves to provide many other properties that allow for the characterization and response of multiple antenna configurations.

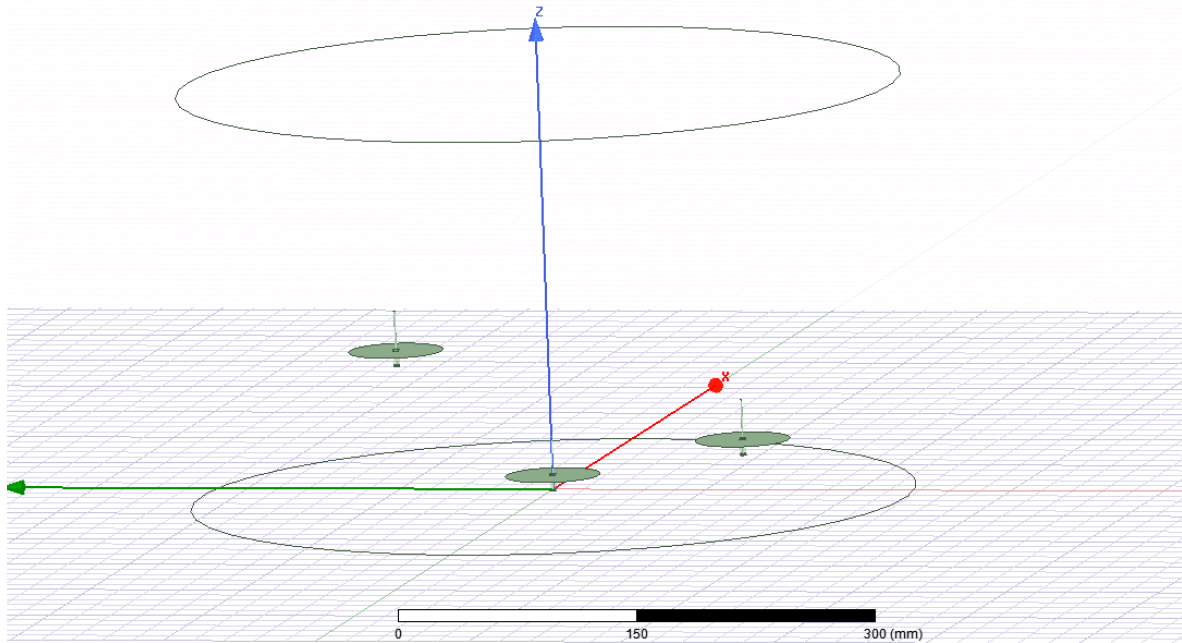


Fig. 7. Three identical monopoles configured in different heights (HFSS)

### DC Offset/Signal Maximization

Implementing the concept of antenna arrays, a two element, angle-fed mixer circuit was designed. The underlying concept beneath this circuit is focused on the basis of wave addition and the relationships of both distance and length (Fig. 8 and Fig. 9). The goal is to develop a control that identifies a location of maximized power reception using the DC offset of two constructive angular incident waves. If location of maximum reception is missed, or delayed, the circuit will have the ability to identify location, recognize fault or distance error, then reposition itself independently so that it can adequately locate the position of maximized DC offset in

regards to the angle of incidence (the input of the circuit). Through iterations similar to the three-element yagi network, when the output of the circuit results in a DC offset pattern with out of phase waves, this signifies that there is pure reflection. In the case of pure reflection, there is no maximization of power, thus signifying a required change of -90 degrees so that the DC offset can better approach a maxima. Every fault in analysis that resulted in destructive interference allowed for fewer ambiguities in circuit characterization. With each iteration, more information is found on the circuit, allowing for adequate readjustments in characterizing input/output requirements for ideal power reception.

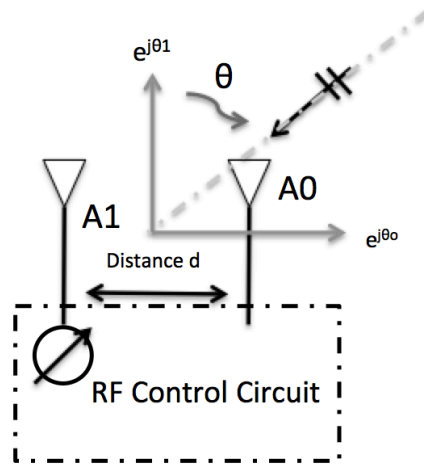


Fig. 8. Concept of Incident Angle Feed for 2 distance separated antennas



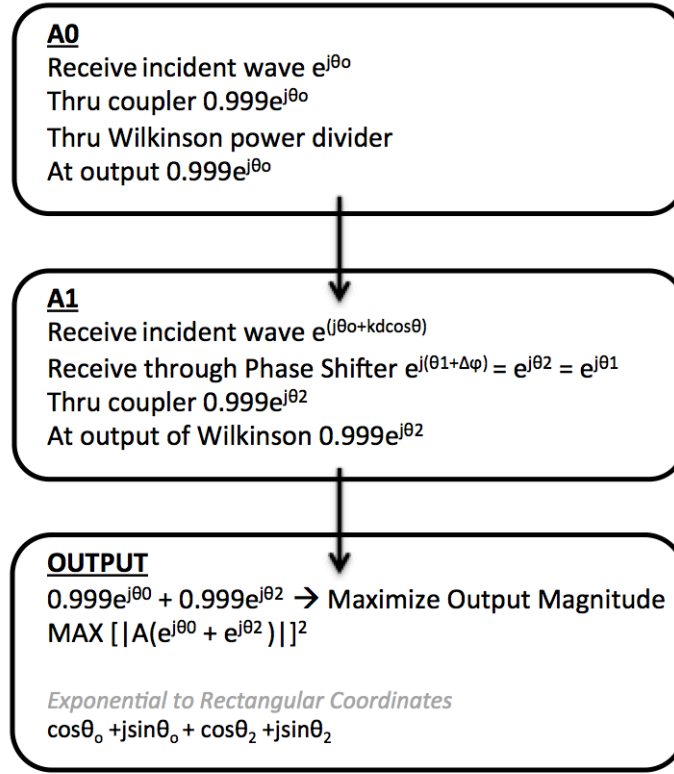


Fig. 9. Calculating magnitude/phase relationships from incident angle

### Control Circuit: ANSYS Circuit Simulator

Implementing the concept of DC offset and wave maxima require the implementation of an RF mixer circuit (Fig. 10). The design of this circuit allows for an angular incident wave to be fed into a decibel coupler that is forwarded to an RF circuit component. While this signal is being transferred, there is a simultaneous feed from a lateral antenna that joins alongside. The two RF signals from both antennas will then be transferred to the mixer in attempts to identify an arbitrary intermediate frequency that is then forwarded to a Wilkinson power divider. The DC offset of both voltage waves will be used as tuning to control the shifting of lateral antenna A to maximize the power input from the combined waves. The circuit is driven by two incident signals that are combined as two RF frequencies into a mixer that are outputted to some arbitrary

intermediate frequency. This coupled intermediate frequency is used as an identifier in locating the circuit's ideal response for maximization. In developing the ANSYS circuit simulations, linear frequency analyses were run sweeping from 1 GHz to 3GHz. The S(2,1) parameters were used to identify circuit response, where the S(3,1) scattering parameters act as the control signal. S(3,4) represents the coupled signal off the ports.

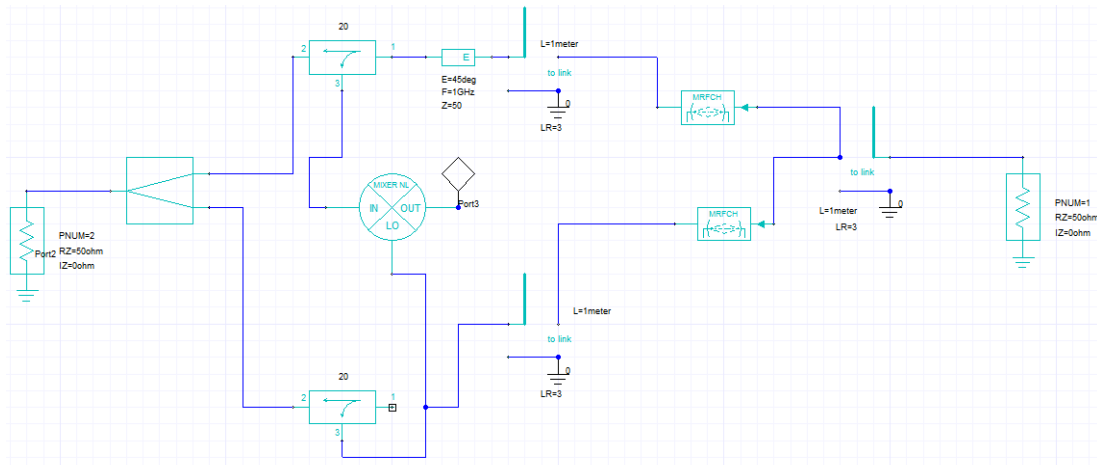


Fig. 10. Mixer Control Circuit designed in ANSYS Circuit Simulator

## CHAPTER III

### RESULTS

#### Wave Maxima

The circuit in ANSYS Circuit simulator was constantly reiterated by adjusting the length of the transmission line from  $0 < l < \frac{\lambda}{2}$ . The signal maxima were identified at the point when both incoming incident waves were added constructively, meaning they were in phase. After readjusting the angle of incidence and transmission line length, it was apparent that at a 50 degree angle of incidence in the circuit, waves are perfectly in phase. When waves were purely out of phase, this means that there is pure reflection of the signal. Waves were out of phase at 130 degrees. By subtracting half a wavelength, the local maxima occurred at approximately 40 degrees electrical length. By adding 40 degrees to the 50-degree angle of incidence the circuit reaches it's maximum.

#### Monopole Characterization

The ideal monopole length in simulation was approx. 24.2457mm of copper. This length was calculated using a 2.92 GHz operating frequency. In characterizing the individual monopole, this length was applied to the array network of multiple monopole configurations. The first configuration was used as a control and evaluates the HFSS simulations of just a single monopole with the same characteristics that were used in the 3-monopole configuration networks. This data was used as a starting point for the basis of design.

The monopole simulation in HFSS was simulated with operation under 2.9 GHz. Fig. 11 and Fig. 12 show these results. Real results are shown in Fig. 13 using the network analyzer.

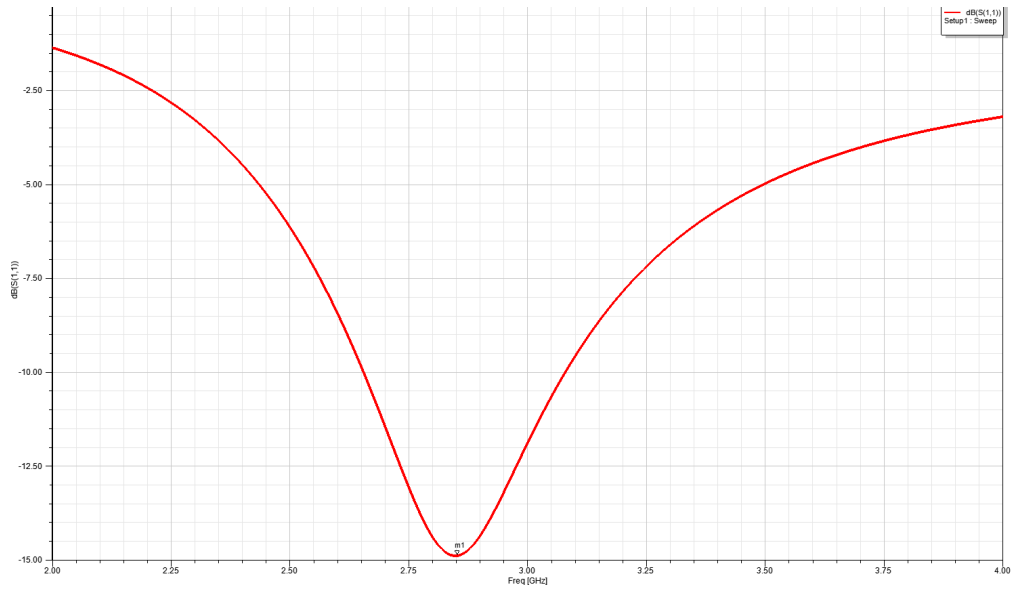


Fig. 11. S-Parameter Plot for Monopole operating under 2.92 GHz

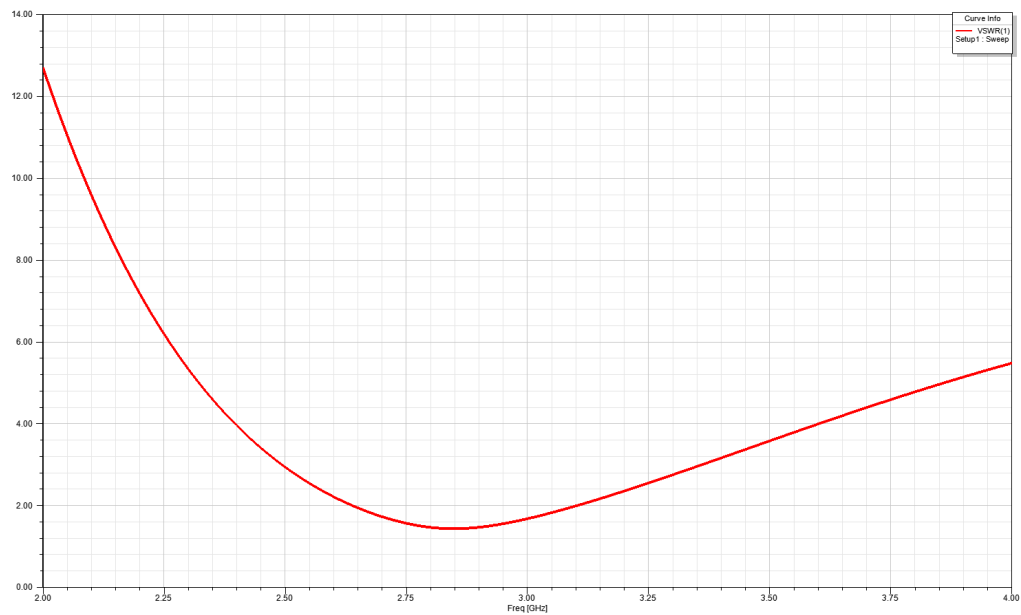


Fig. 12. VSWR for monopole operating under 2.92 GHz

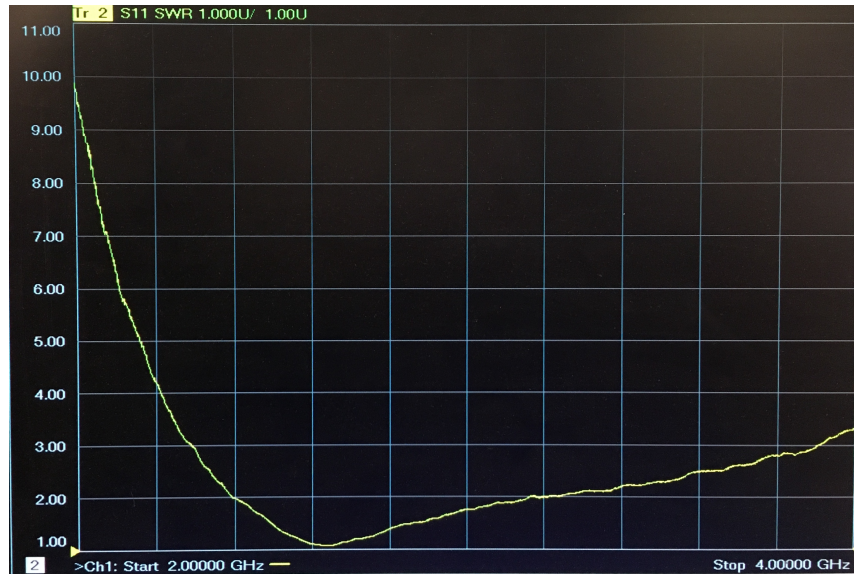


Fig. 13. VSWR of Fabricated monopole (2.5GHz) on Network Analyzer

### 3 Identical Monopoles in Parallel: Characterization

Another characterization test was distance. The three parallel monopoles were simulated in HFSS to identify the effect of lateral distance. HFSS simulations were run using restrictive parameters sweeping 10mm to 20mm with 5mm steps. The following plots describe the effect of distance on the radiated power and reflection (Fig. 14, Fig. 15, Fig. 16, and Fig.17).

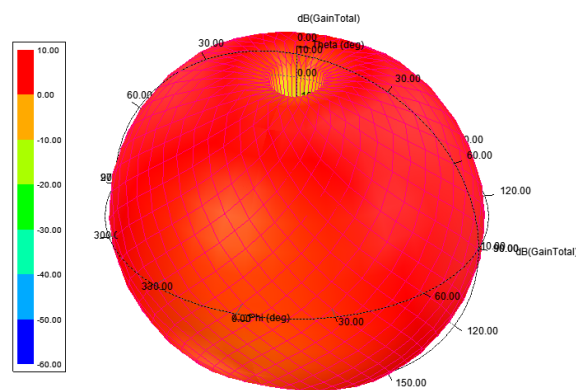


Fig. 14. Radiation plot of 3 identical monopoles in parallel on HFSS

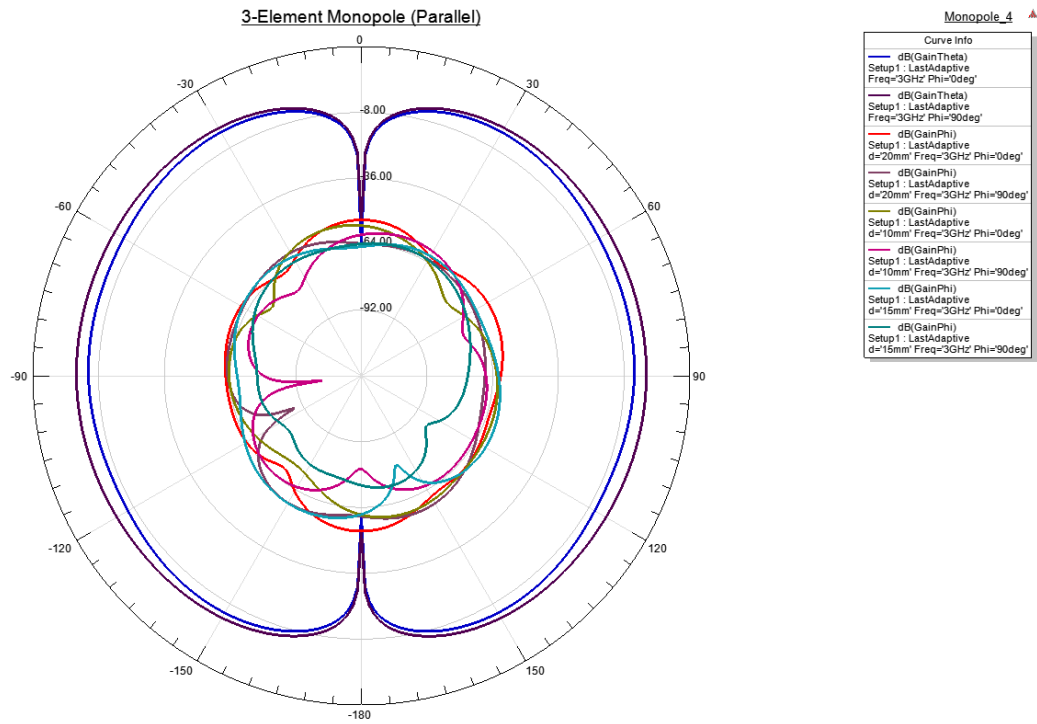


Fig. 15. Radiation plot of parallel monopoles (Distance sweep 1)

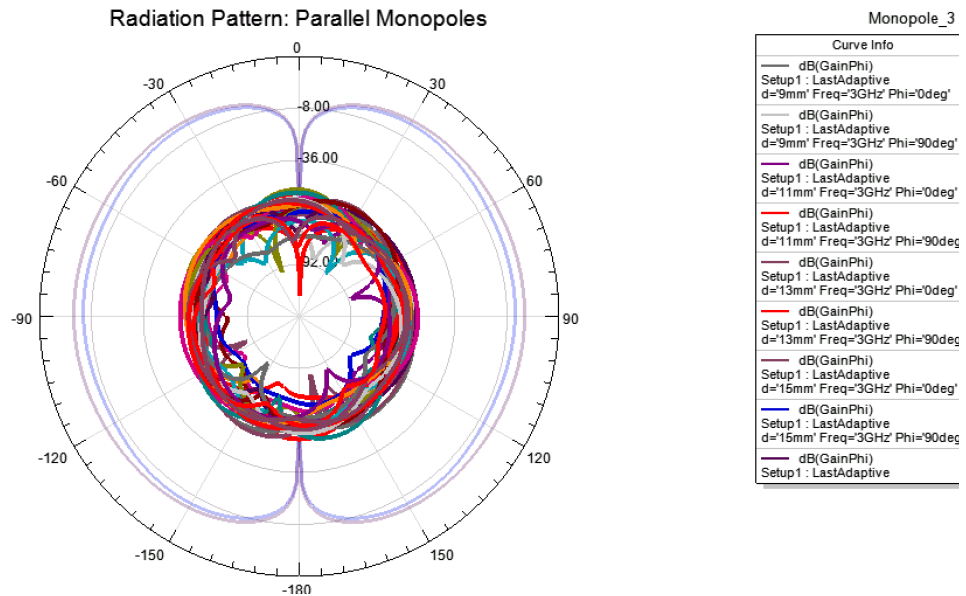


Fig. 16. Radiation plot of parallel monopoles (Distance Sweep 2)

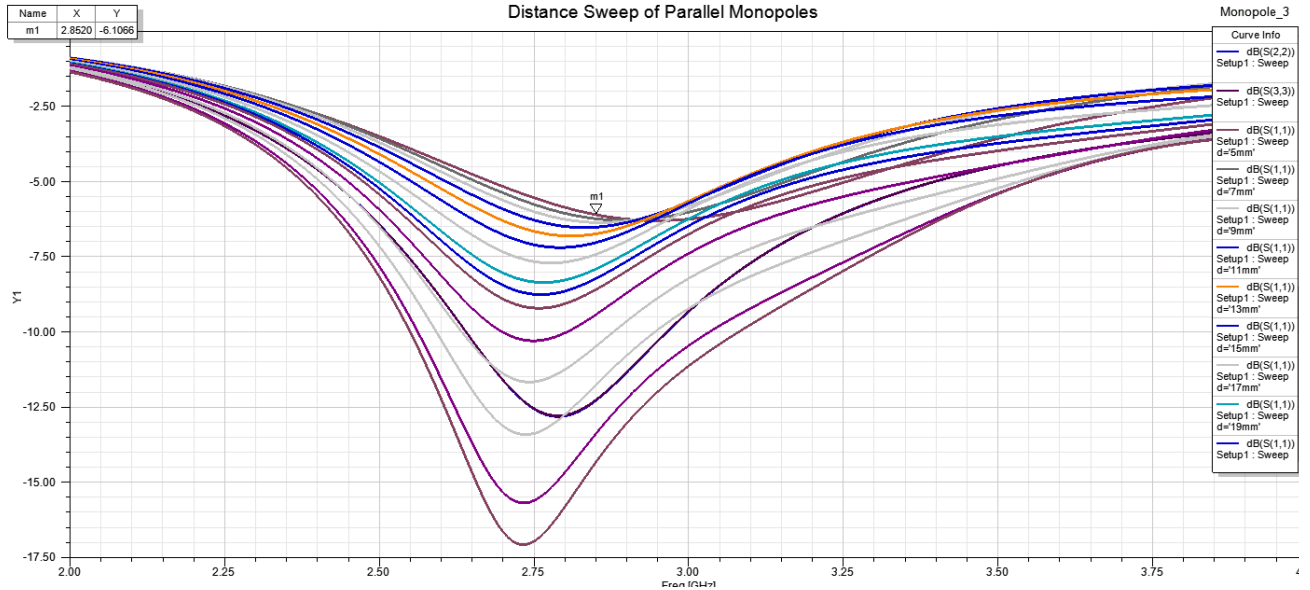


Fig. 17. S(1,1) Parameter of distance sweep between identical monopoles

Looking at the S parameters, the S(1,1) plots reveal the amount of power going through the system. When the monopoles were located 30mm apart, they had the greatest power transfer. This result reveals that it is necessary to test more conditions for parameters. Height, angle of incidence, and distance parameters need to be swept through multiple iterations in conjunction with the adequate performance of the RF mixer circuit as a control.

### 3 Identical Monopoles: Height Adjustments

Multiple angular positions and heights were tested using the three identical monopoles from prior characterization methods. Again, as the monopoles were farther apart (singular and height differences), their power reception was greater. Due to time constraints and duration of HFSS testing for large parameter sweeps,

minimal tests were performed. Following the primary sweep, a greater variety of configuration parameters will be swept for further analysis.

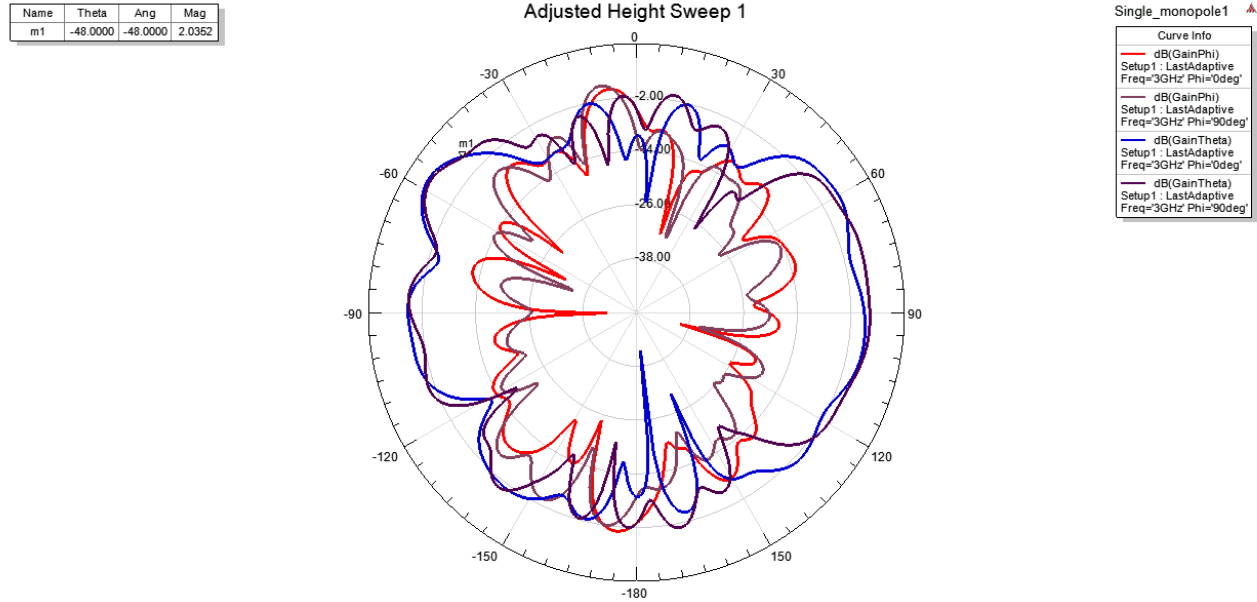


Fig. 18. Radiation plot of multiple monopoles configured at different heights



## **CHAPTER IV**

### **CONCLUSION**

The purpose of this project was to design a centralized antenna within interfering incident signals with the ability to reconfigure itself over time for maximal power reception. This research requires consistent testing of various parameters that include incident angles, wave maxima location, monopole characteristics, and response/control of an RF circuit. Due to time constraints, further fabrication of this antenna could not be completed. But the characterization of different monopole configurations were successfully completed in simulation alongside the design of a functional RF mixer circuit that constructs two incident signals and takes the maximized magnitude to readjust the movement of antenna for reconfiguration. After observational testing and analysis, the next step in this research serves to combine the RF circuit with the HFSS simulations and allow for varying configurations to be tested in conjunction with the circuit. Upon adequate simulation results, the antenna can further proceed with fabrication and be tested using the network analyzer and anechoic chamber.

## REFERENCES

- [1] R. Harrington, "Reactively controlled directive arrays," in *IEEE Transactions on Antennas and Propagation*, vol. 26, no. 3, pp. 390-395, May 1978
- [2] H. Kawakami and T. Ohira, "Electrically steerable passive array radiator (ESPAR) antennas," in *IEEE Antennas and Propagation Magazine*, vol. 47, no. 2, pp. 43-50, April 2005
- [3] K. Gyoda, T. Ohira, "Design of Electronically Steerable Passive Array Radiator (ESPAR) Antennas", *IEEE International Symposium on Antennas and Propagation Digest*, pp. 922-925, 2000-July.
- [4] A.Kausar, M.Cheema, S. Kausar, H.Rehman, T. Hassan, "ESPAR Antenna System Designing & Simulation," in *Adaptive Beam Forming Antenna System for Target Tracking*, pp.156-159, 2014.
- [5] "Antenna Arrays." *Antenna Arrays*, [www.ece.rutgers.edu/~orfanidi/ewa/ch22.pdf](http://www.ece.rutgers.edu/~orfanidi/ewa/ch22.pdf).
- [6] "Antenna Arrays and Propagation." [www.faculty.jacobs-university.de/jwallace/xwallace/courses/ap/ch5.pdf](http://www.faculty.jacobs-university.de/jwallace/xwallace/courses/ap/ch5.pdf).
- [7] M.Modaresi, "Design and Fabrication of a High-Gain Microstrip-Fed Yagi-Uda Antenna." 11 July 2005.
- [8] J.Winters, "Understanding MIMO: Part II." *EETimes*, 28 Apr. 2005, [www.eetimes.com/document.asp?doc\\_id=1273368](http://www.eetimes.com/document.asp?doc_id=1273368).